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Equipment purchased under this contract has been used by approximately twelve researchers (two post-docs, eight graduate students, two undergraduates) for several reseach activities, as summarized briefly below.

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SCHOOL OF
ELECTRICAL AND
COMPUTER ENGINEERING

April 29, 1999

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Dear Sir:

Please find enclosed the final report for our DURIP contract F49620-97-1-0400.

Best regards,

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AMW/dld

Enclosure

cc: ONRRO
Purdue Sponsored Program Services

Final Report

Air Force Office of Scientific Research
F49620-97-1-0400

Instrumentation for Research on High-Speed Optical Transmultiplexing and Coding for Optoelectronic Computer Networking

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4-30-99

Andrew M. Weiner
Principal Investigator

I. Acquired equipment

We acquired the following equipment using funds from this contract:

Item	Quantity	Vendor	Description	Cost
1	1	Kapteyn-Murnane Laboratories	Femtosecond titanium:sapphire laser	$18,399 ($3843 from this contract)
2	1	Ortel Corporation	4-laser WDM transmitter array	$17,640
3	1	Veritech Microwave	2.5 Gb/s driver for light modulator	$1553
4	2	SDL Optics	980 nm laser modules	$8943 ($7966 from this contract)
5	1	Uniphase Telecom Products	2.5 Gb/s light modulator	$4031
6	1	Princeton Instruments	CCD camera	$28,800
7	1	Princeton Instruments	photodiode array controller	$4450
8	2	EG&G Princeton Applied Research	lockin amplifiers	$8009
9	1	Hewlett-Packard	3 Gb/s error analyzer	$79,877 ($17,001 from this contract)
10	1	Spectra Physics	Millenia X diode-pumped solid state laser	$74,500 ($37,250 from this contract)
11	1	Newport Corporation	stepper motor translations tage with controller	$9013
12	2	Naptech	100 MHz oscilloscopes	$1445
13	2	Micron Electronics	computers	$3904
14	1	ILX Lightwave	contorl electronics for laser modules	$2425

There are some significant differences between the list of equipment purchased and the equipment list in the proposal. The most significant differences are as follows:

a) The diode-pumped solid-state laser (item 10 above) was purchased in part using other funds, which allowed acquisition of a higher power laser than originally budgeted, while spending over $12,000 less from this contract than originally budgeted.

b) An optical table, budgeted in the proposal at $13,875, was purchased using other funds.

c) A CCD camera array and a new photodiode array controller (items 6 and 7 above) were purchased from Princeton Instruments for $33,250 in place of an optical spectrum analyzer originally budgeted at $41,300 from Hewlett-Packard.

These savings were applied to purchase other needed equipment, as follows:

d) Required lightwave communications components (items 3, 4, 4, and 14) were purchased using ~$16,0000 from this contract.

e) We had the opportunity to purchase a 3 Gb/s error rate analyzer at the significantly discounted price of $79,900. We made this purchase using $17,000 from this contract supplementing other funds. This instrument significantly extends our capabilities to investigate high speed optical communication systems.

II. Research projects summary

Equipment purchased under this contract has been used by approximately twelve researchers (two post-docs, eight graduate students, two undergraduates) for several research activities, as summarized briefly below.

II.A. Ultrafast optical transmultiplexing using space-time processing

A key goal of our research is to demonstrate all-optical methods for generation, processing, and transmultiplexing (data format conversion) of ultrafast lightwave signals. Recently our effort has focused on incorporating pixellated optoelectronic modulator arrays into femtosecond pulse shaping systems. This work could lead to pulse shaping systems generating (or processing) data signals and packets which can be reprogrammed at rates in the nanosecond regime. This would fill an important need in both TDM packet networks and bit-parallel WDM links. Additional, this may result in additional processing power in optical pulse shaping systems through the use of smart pixel device arrays.

Examples of our work using equipment from this contract are as follows:

- We have constructed and demonstrated a direct space-to-time femtosecond pulse shaping apparatus where the generated waveform is a directly scaled version of a spatial masking pattern. This is in contrast to the usual pulse shaping geometry where the output waveform is determined by the Fourier transform of the spatial masking pattern. Our current configuration is preferred for applications involving generation of reprogrammable pulse packets for use in TDM optical communications, because each pulse can be associated with an individual element on a high-speed optoelectronic modulator array. We have also performed the first experiments demonstrating the dispersive properties of the direct space-to-time pulse shaper, which is important in order to control the chirps of the generated pulse packets.

- We have performed static and at-speed tests of a GaAs-MQW/Si-CMOS ("CMOS-SEED") smart pixel array fabricated through a Bell Labs-Lucent foundry process. This array will soon be tested in the new pulse shaper noted above.

- We have analyzed the conditions necessary to optimize the efficiency of a femtosecond time-to-space converter based on second harmonic generation within a pulse shaper apparatus. Based on these results, we performed experiments demonstrating a second harmonic conversion efficiency of nearly 60% in the time-to-space conversion process; this efficiency is 500 times greater than that obtained in previous experiments performed by others.

II.B. Ultrashort pulse code-division multiple-access (CDMA) optical communications

Our research aims at experimental tests of an ultrashort pulse code-division, multiple-access (CDMA) optical communications system and of the devices needed to implement such a system. We have obtained several key results during the period of this contracted, listed below:

- For the first time we have demonstrated single user, ultrashort pulse CDMA transmission of sub-500-fs pulses over a multi-kilometer fiber link, including spectral encoding, 2.5 km dispersion compensated fiber transmission, spectral decoding, and nonlinear optical thresholding. With the entire system we observed contrast ratios exceeding 30 dB after the fiber optic thresholder, close to what we achieved with the thresholder operating alone.
- We have investigated nonlinearities which arise in dispersion compensated fiber links with large broadening and recompression ratios of several hundred [ref]. These experiments are important to establish power budgets and limitations in the overall CDMA system. Although fiber nonlinearities have been extensively investigated by others in the context of fiber and grating pulse compression and soliton propagation, the parameter range we are investigating, with weak nonlinearities and very large broadening and recompression ratios, remained almost completely unexplored.

II.C. Femtosecond optical manipulation of terahertz (THz) radiation

We are engaged in a program to investigate the use of shaped pulses to manipulate THz radiation emitted by biased photoconductor samples as well as via optical rectification from second order nonlinear optical materials. Previously we demonstrated several interesting forms of THz waveform control from photoconductive samples, e.g., tunable narrowband THz radiation in the 750 GHz-1.2 THz frequency range. We have also shown that the use of femtosecond pulse trains allows a considerable enhancement of the peak THz power spectral density through avoidance of saturation effects. During the period of the current contract, we compared THz waveforms measured by using photoconductive dipole antennas and by using electro-optic sampling. These measurements elucidate the role of the frequency-dependent antenna response in waveform measurements using photoconductive receivers. We also performed experiments clearly showing the evolution of the THz waveform as the emitter-receiver separation is increased from the near-field to the far-field regime. Finally, we collaborated with researchers at Los Alamos National Laboratories to investigate THz generation using pulse trains from amplified femtosecond sources and large aperture photoconductive emitters. This extends our previous work on enhancing the peak THz spectral density to a much higher power regime.

II.D. Laser speckle for characterization of and imaging within optically scattering media

We are investigating a new technique for characterization of and imaging within dense optically scattering media based on observation of laser speckle statistics at the output of the medium. The key concept is that the modulation depth of the laser speckle depends on the variance in the photon travel times through the medium relative to the laser coherence time. Therefore, the speckle statistics are sensitive to inhomogenities within the scattering medium. During the period of this contract, we have performed experiments demonstrating the use of a narrow-linewidth but tunable laser diode to synthesize light with a variable and controllable optical bandwidth (and hence a controllable coherence time). Our experiments further demonstrated the use of this coherence width synthesized source for characterization of highly scattering media.

II.E. Femtosecond second harmonic generation in thick nonlinear crystals

We investigated second harmonic generation of femtosecond pulses using thick nonlinear crystals with large group velocity walkoff. Despite the long history of second harmonic generation, surprisingly it appears that the parameter space examined here had previously seen little experimental study. Our experiments using femtosecond pulses from a titanium:sapphire laser and a $KNbO_3$ nonlinear crystal demonstrated nearly 60% conversion efficiency into the blue for modest average input powers of only 300 mW. This high efficiency using a very simple experimental apparatus, coupled with the rapid improvements in commercial femtosecond laser technology, may lead to consideration of femtosecond second harmonic generation as a new approach for generation of blue and ultraviolet light for applications such as lithography, holographic recording, and industrial inspection where the pulse width is not critical. In addition, our experiments revealed a new efficiency vs. focusing relationship which had not previously been observed in second harmonic generation.